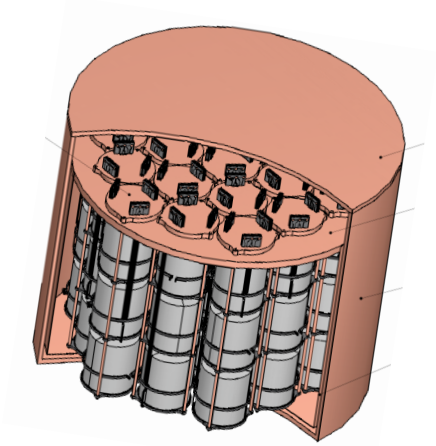
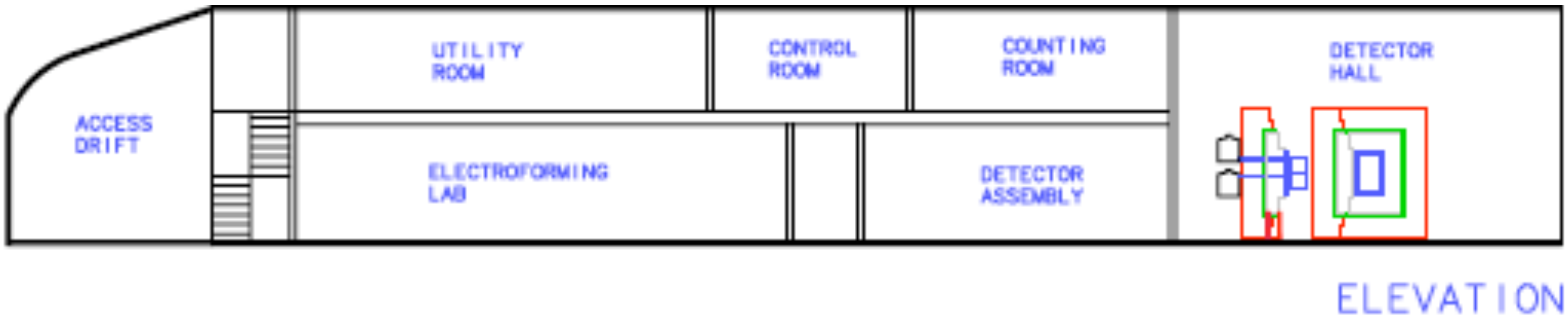
The Majorana Neutrinoless double β-decay experiment

- Neutrinoless $\beta\beta$-decay
- Majorana Overview
- Facility needs
- Schedule
- Summary





Homestake Scientific PAC

February 10, 2006

J.F. Wilkerson
on behalf of the Majorana Collaboration

Neutrinoless $\beta\beta$-decay Motivation

The recent discoveries of solar, reactor, and atmospheric neutrino oscillations provide a compelling argument for new $0\nu\beta\beta$-decay experiments with increased sensitivity.

$0\nu\beta\beta$-decay probes fundamental physics.

- It is the only technique able to determine if neutrinos might be their own anti-particles, or Majorana particles.
- If Majorana particles, $0\nu\beta\beta$ ultimately offers the most promising method for determining the overall absolute neutrino mass scale.
- Tests one of nature's most fundamental symmetries, lepton number conservation.

U.S. Neutrino Scientific Assessment Group

Recommendation: *The Neutrino Scientific Assessment Group recommends that the highest priority for the first phase of a neutrino-less double beta decay program is to support research in two or more neutrino-less double beta decay experiments to explore the region of degenerate neutrino masses* ($\langle m_{\beta\beta}\rangle > 100$ meV). *The knowledge gained and the technology developed in the first phase should then be used in a second phase to extend the exploration into the inverted hierarchy region of neutrino masses* ($\langle m_{\beta\beta}\rangle > 10-20$ meV) *with a single experiment*.

Reviewed Five Experiments related to U.S. program.

In terms of funding (alphabetical order)

High priority: CUORE, EXO, Majorana

DOE gave $0\nu\beta\beta$ "mission critical need" (CD-0) in Dec. 2006

See DOE NSAC Web Page for the Report.

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Note: Red text indicates students

Advantages for Majorana

^{76}Ge offers an excellent combination of capabilities and sensitivities. Majorana is preparing to proceed, with demonstrated technologies.

- Favorable nuclear matrix element $\langle M'^{0\nu}\rangle = 2.4$ [Rod05].
- Reasonably slow $2\nu\beta\beta$ rate ($T_{1/2} = 1.4 \times 10^{21}$ y).
- Demonstrated ability to enrich from 7.44% to 86%.
- Ge as source & detector.
- Elemental Ge maximizes the source-to-total mass ratio.
- Intrinsic high-purity Ge diodes.
- Excellent energy resolution — 0.16% at 2.039 MeV
- Powerful background rejection.
  Segmentation, granularity, timing, pulse shape discrimination
- Best limits on $0\nu\beta\beta$ – decay used Ge (IGEX & Heidelberg-Moscow)
  $T_{1/2} > 1.9 \times 10^{25}$ y (90%CL)
- Well-understood technologies
  - Commercial Ge diodes
  - Large Ge arrays (GRETINA, Gammasphere)

The Majorana Scientific Goals

Search for neutrinoless double-beta decay in ^{76}Ge

- Probe the quasi-degenerate neutrino mass region of 100 meV.
- Definitively test the Klapdor-Kleingrothaus ^{76}Ge claim in the 400 meV region ($T_{1/2} = 1.2 \cdot 10^{25}$ y).
- Demonstrate backgrounds that would justify scaling up to a 1-ton or larger detector.

The Majorana Experiment Overview

First phase - a 120 kg Experiment

- Reference Design
  - 114 segmented, n-type, 86% enriched ^{76}Ge crystals.
  - 2 independent, ultra-clean, electroformed Cu cryostat modules.
  - Enclosed in a low-background passive shield and active veto.
  - Located deep underground (4500 - 6000 mwe).
- Background Specification in the $0\nu\beta\beta$ peak region of interest (4 keV at 2039 keV)

  1 count/t-y
- Expected Sensitivity to $0\nu\beta\beta$ (for ~5 years, or 0.46 t-y of ^{76}Ge exposure)

  $T_{1/2}$ >= 5.5×10^{26} y (90% CL)

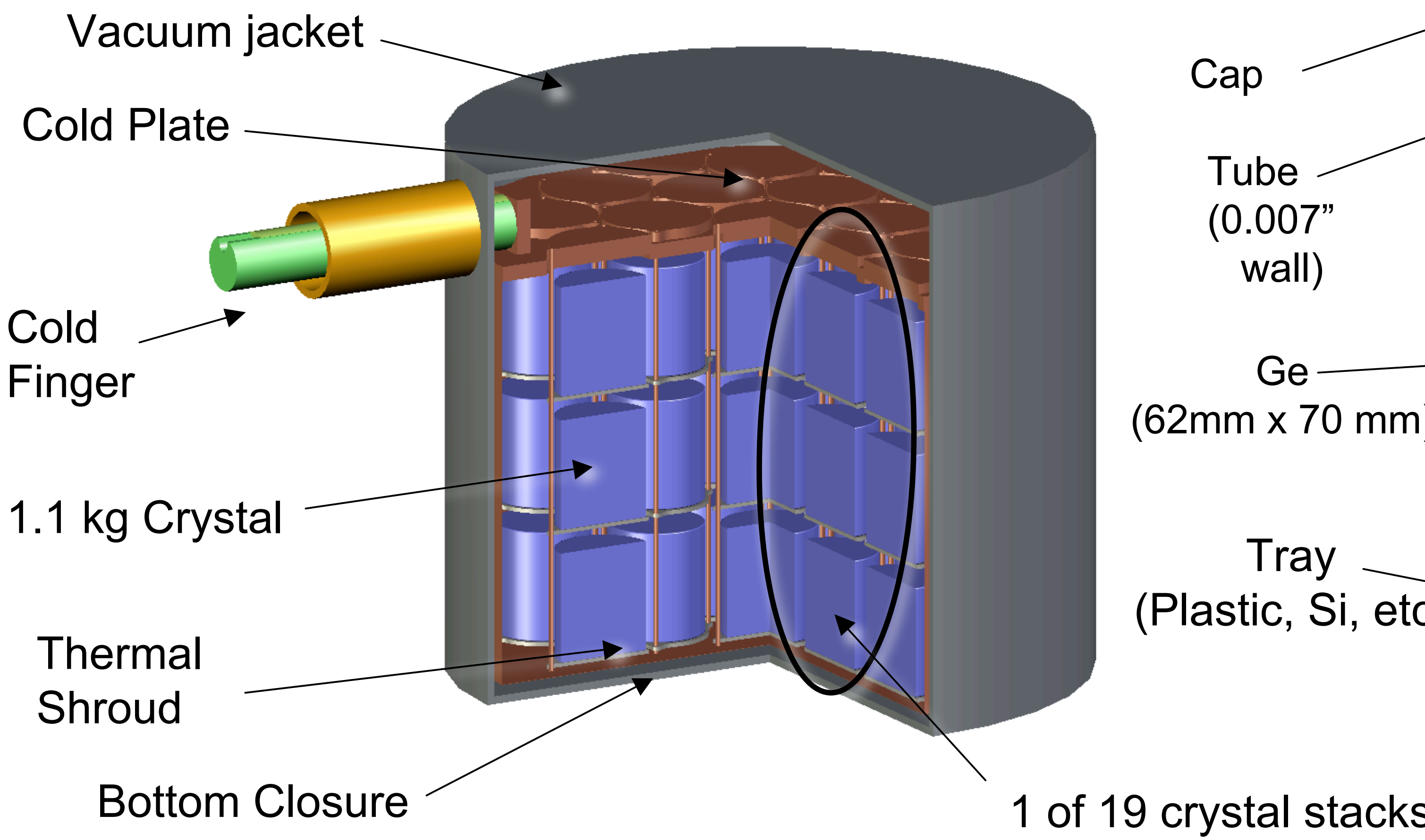
  $\langle m_\nu \rangle$ < 100 meV (90% CL) ([Rod05] RQRPA matrix elements)

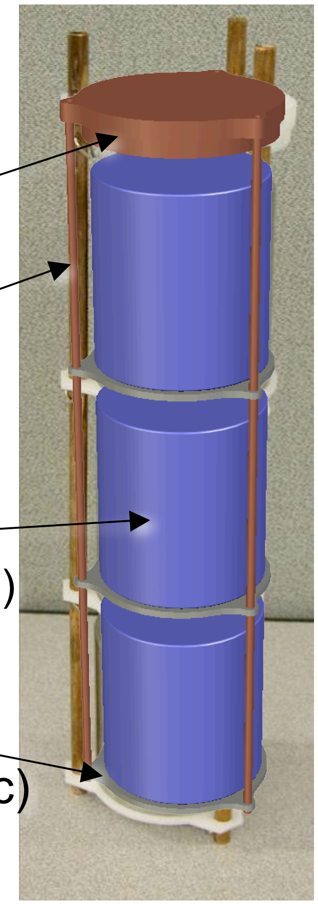
  or a 10% measurement assuming a 400 meV value.

Majorana is scalable, allowing expansion to 1000 kg.

The Majorana Modular Approach

- 57 crystal module
  - Conventional vacuum cryostat made with electroformed Cu.
  - Three-crystal stack are individually removable.





Majorana Project Summary

- The Majorana ^{76}Ge design is scalable to the 1000 kg level.
- Compared to best previous $0\nu\beta\beta$ experiments, M120
  - has 12 times more Ge
  - 8 times lower radioactivity
  - Improved design and detector technology should yield 30 times better background rejection.
- With M120 we can reach a lifetime limit of 5.5×10^{26} y (90% CL) corresponding to a neutrino mass of 100 meV or perform a 10% measurement assuming a 400 meV value.
- Plan to submit our proposal to DOE in March or April 2006.

For more detailed documents see:

http://ewiserver.npl.washington.edu/majorana/NuSAG/documents.html

Key issue for Majorana - backgrounds

- Sensitivity to $0\nu\beta\beta$ decay is ultimately limited by S-to-B.
  - **Goal: ~400 times lower background than previous ^{76}Ge experiments.**
  - Approach: Reduction or active discrimination of background sources
  - **Key specifications:**
    - Cu at < 1 μBq/kg (current measured value ≤ 8 μBq/kg)
    - Cleanliness on a large scale (100's of kg)

- Must directly reduce intrinsic, extrinsic, & cosmogenic activities.
  - Go deep — reduced μ's & related induced activities
    - neutrons are a particular worry
  - Select and use ultra-pure materials
    - Process and fabricate materials underground
  - Minimize and control radon exposure
  - Minimize and control dust exposure (Class 100 cleanrooms)

Majorana Infrastructure needs

Three areas of underground activity:

1. **Fabrication**

   Electroforming copper parts

   Low-background acceptance testing

2. **Assembly**

   Putting it together

   Making it work

3. **Data taking** - staged by module

   60 kg ↘

   120 kg ↘

   ?

Majorana site related activities

- **Underground Activities**
  - Electroforming of the detector assembly and shielding copper components.
  - Machining of the detector assembly and shielding copper components.
  - Low background counting
  - Storage of components in a radon free environment.
  - Characterization of the Ge detectors
  - Testing of the bare Ge Detectors.
  - Assembly of the Ge detectors into cryostats.
  - Testing of the Ge detector strings
  - Assembly of the Ge detector strings into cryostats.
  - Assembly of the detector cryostat modules into monoliths.
  - Final QA of components before assembly into detector systems?
  - Assembly of monoliths into the multilith.
  - Assembly of the detector multilith (detector blockhouse) and it's associated veto shielding.
  - Calibration of
    - Bare crystals
    - Fully assembled detector.
  - Operations (4+ years)

Majorana site related activities

- **Surface Activities**
  - Receiving of detector components and materials to go underground.
  - Initial counting of components
  - Surface control and monitoring of experiment.
  - Data processing and data storage.
  - Radon emanation of components?

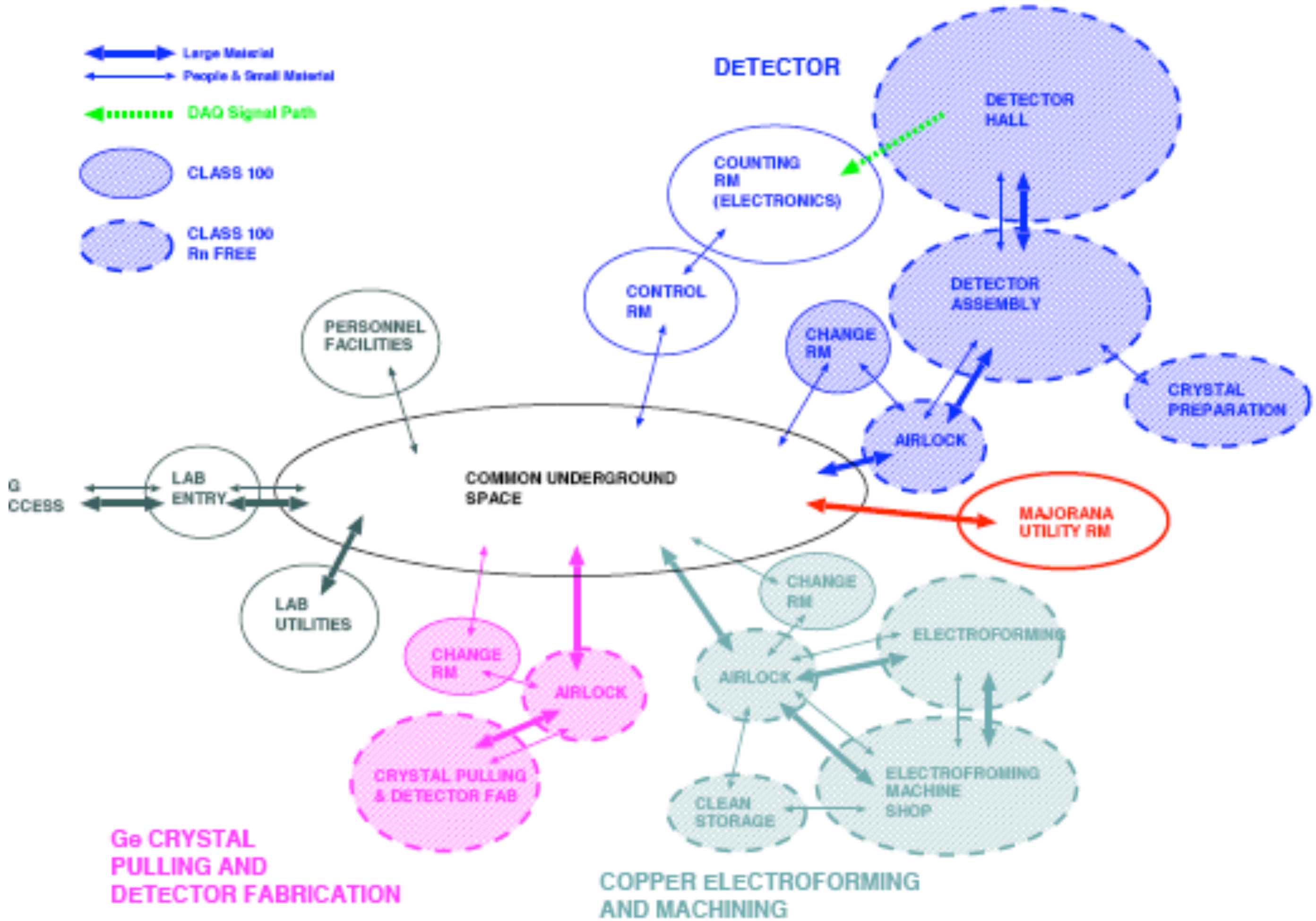
Majorana Infrastructure Estimates

Currently we are refining the FTE estimates based on the detailed WBS and safety reviews

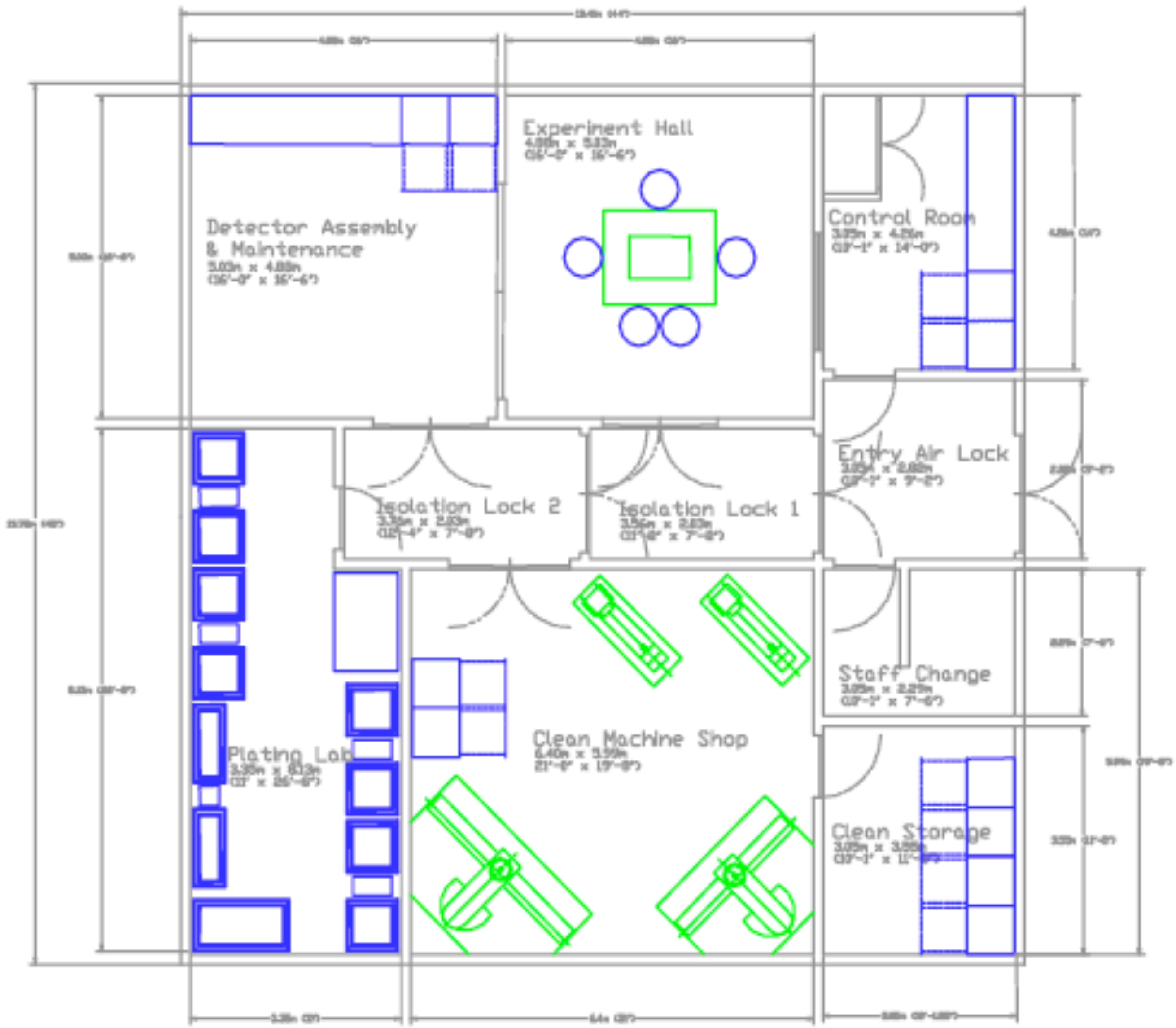
Location	Space (m)	Power (kW)	Air Quality	Occupancy (People/shift)
control room	5x4x3	30 (ups)	regular lab	2 (2 shifts)
detector	5x5x3	2 (ups)	class 100, radon free	0-2 (2 shifts)
assembly	5x5x3	8 (ups)	class 100, radon free	0-4 (2 shifts)
entry	4x4x3	1	HEPA	-
storage (dirty)	4x4x3	1	regular lab	-
storage (clean)	4x4x3	1	class 100, radon free	-
electroforming	4x10x3	40	class 2,000, radon free	0-4 (2 shifts)
shop	4x10x3	24	class 2,000, radon free	0-4 (2 shifts)
entry	4x10x3	1	HEPA	-
Total	214 m^3	108		20-40*

*Peak year estimate.

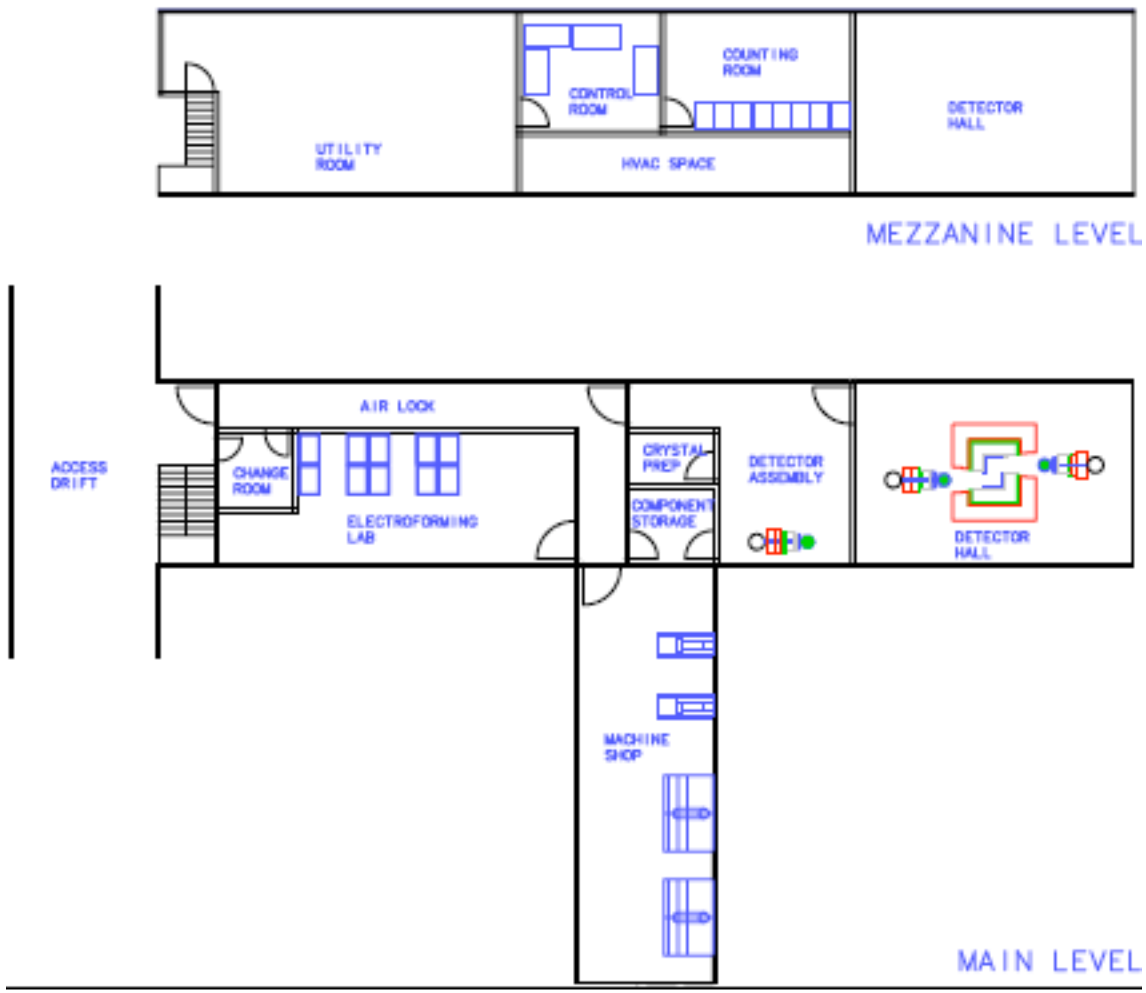
Activity requirements & relationships



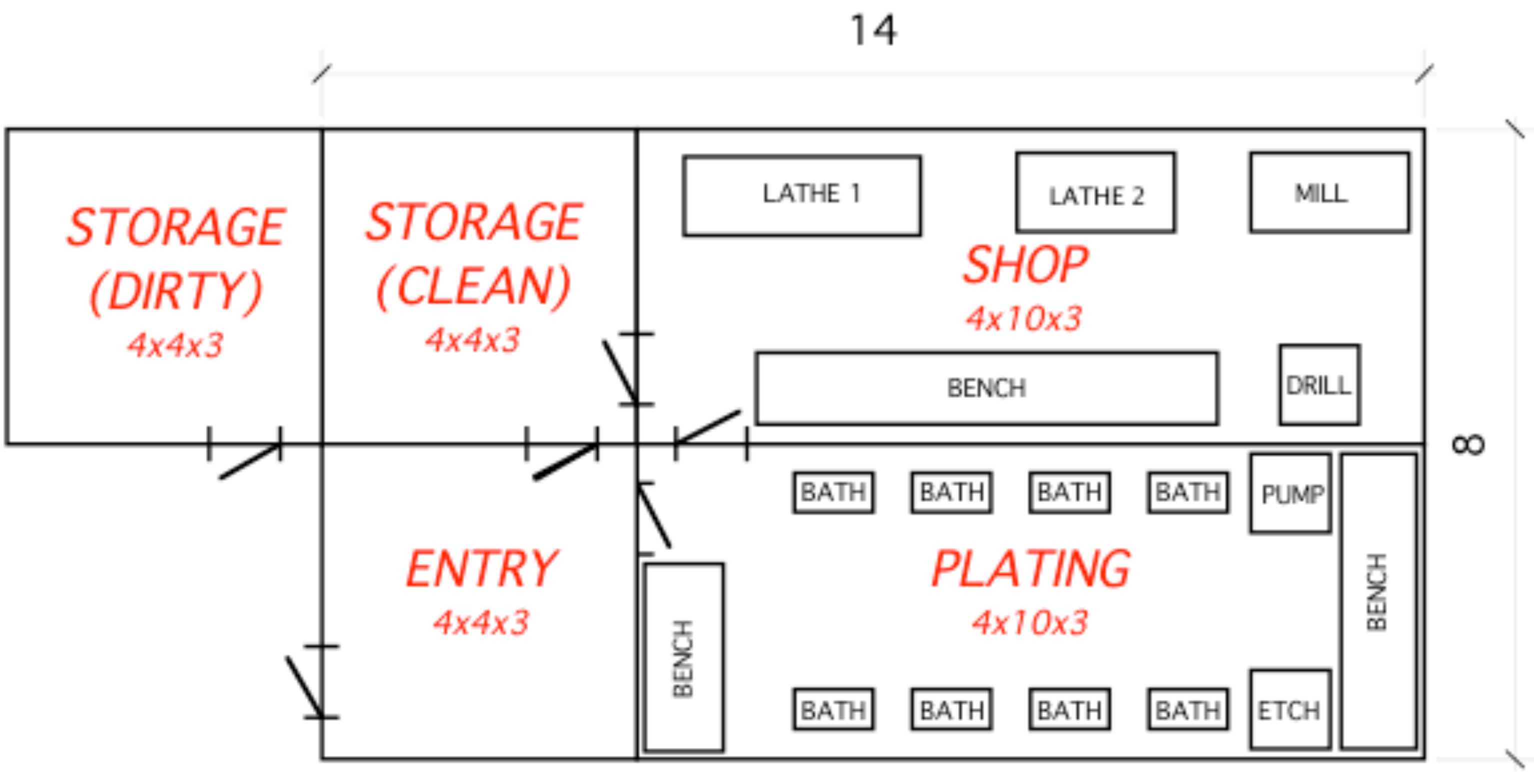
A generic underground Majorana layout



A more "engineered" underground layout



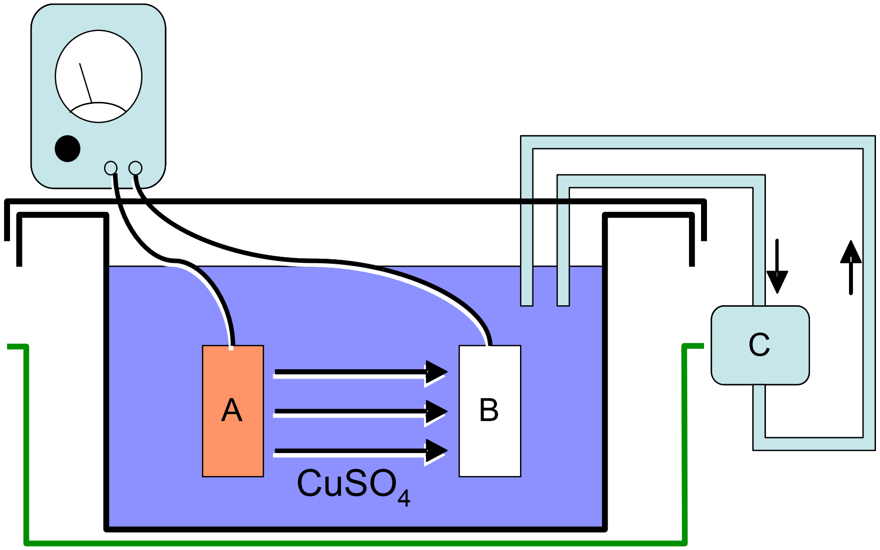
Majorana Layout - Fabrication areas



Dimensions in meters

Electroforming copper - key elements

$^{232}Th < 1\mu Bq/kg$



Current density ~ 40mA/cm^2
Plating rate ~ 0.05 mm/hr

- Semiconductor-grade acids
- Copper sulfate purified by recrystallization
- Baths circulated with continuous microfiltration to remove oxides and precipitates
- Continuous barium scavenge removes radium
- Cover gas in plating tanks reduces oxide formation
- Periodic surface machining during production minimizes dendritic growth
- H_2O_2 cleaning, citric acid passivation

Electroforming copper - Infrastructure

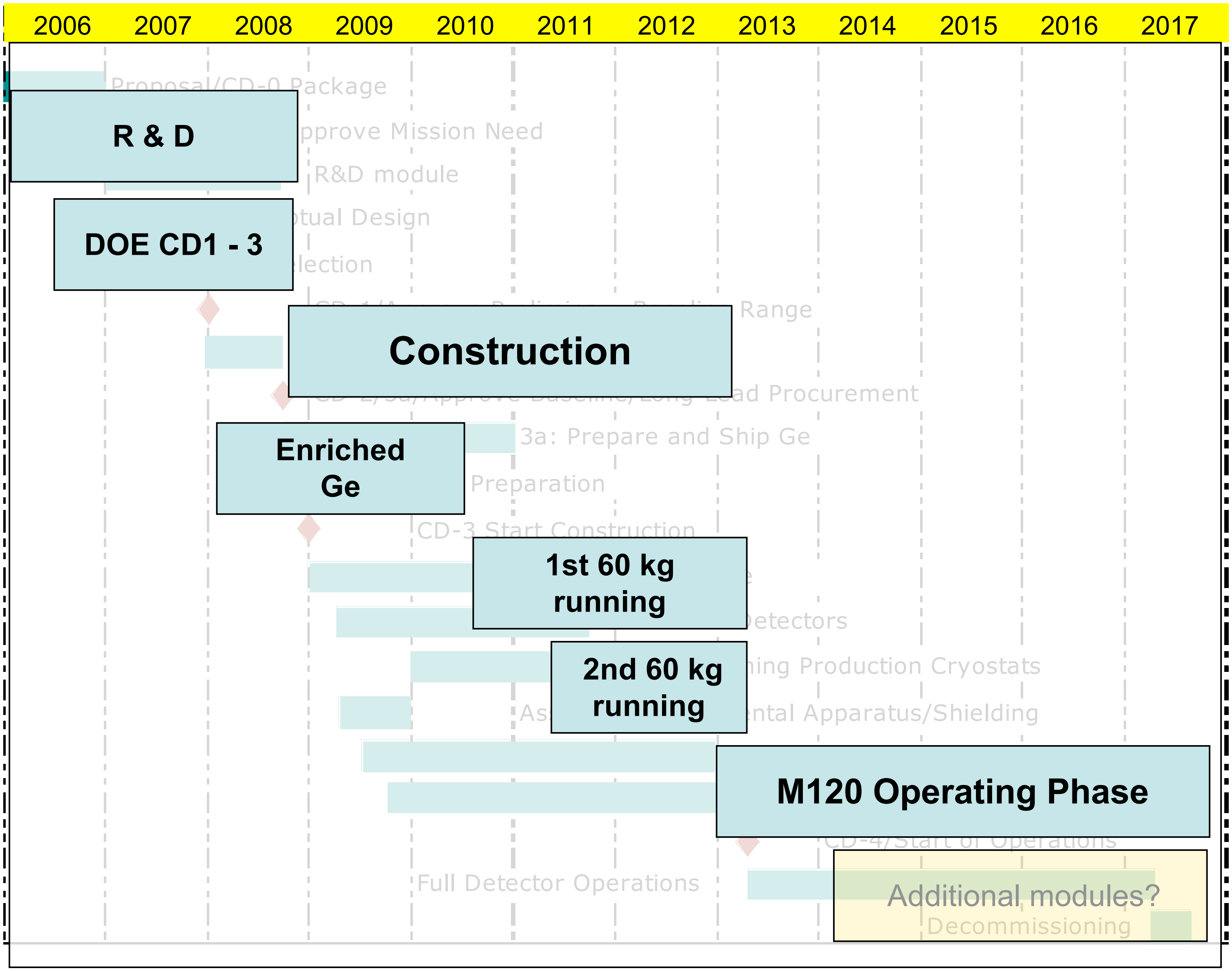
Cold plate for the MEGA feasibility study at WIPP, NM.

- HEPA-filtered air supply
- Radon-scrubbed air for lowest-level work
- Fume extractor for etching
- Flammable and hazardous gas sensors
- Radon-proof storage lockers with purge gas and vacuum capability
- Etching and acid storage
- Spill containment lining
- Milli-Q water system w/DI supply water
- Air-lock entry, washable walls
- Air-conditioning to ~ 20 C
- 10^{-6} Torr dry vacuum system

Majorana - Special considerations

- Cryogens (≤ 1000 liters)
- Waste gasses (electroforming, etching)
- Acids (electroforming)
- Solvents (alcohol, acetone…)
- Oxidizers (dilute H_2O_2 cleaner)
- Lead (shielding)
- Flammable plastics (veto)
- Compressed gasses
- Radon-"free" inert cover gasses (LN_2?)
- Radioactive sources
- Integrated approach to safety management

Schedule (contingent on proposal approval and funding)



Majorana Summary

- A decision to proceed with the Majorana ^{76}Ge Project should be made in 2006, if positive, then under an optimistic funding profile, we would plan to start construction in FY08 and allow first module turn-on in FY 2010-11.
- We have previously submitted a letter of interest to SNOLab
  - The SNOLAB Experiments Advisory Committee stated that they: "*'strongly endorse' this project as a part of our programme*"
- Majorana intends to make a site selection decision after we understand our funding prospects/profile.
  - Risk factors : Lab access beyond 2012
  - Cost factors : International partners, available facilities, support provided by the site, local labor costs, backgrounds (depth, more sophisticated active/passive shield), transportation, …
  - Other considerations : Future scalability, potential alternative shielding techniques,